II. *A Diſcourſe concerning a Method of Diſcovering the true Moment of the Sun's Ingreſs into the Tropical Signs. By* E. Halley.

IT may perhaps paſs for a Paradox, if not ſeem extravagant, if I ſhould aſſert that it is an eaſier matter to be aſſured of the moments of the Tropicks, or of the times of the *Sun's* entrance into *Cancer* and *Capricorn*, than it is to obſerve the true times of the Equinoctials or Ingreſs into *Aries* and *Libra*. I know the Opinion both of Ancient and Modern Aſtronomers to the contrary; *Ptolemy* ſays expreſly, Τὰς τῶν τροπῶν τηρήσεις δυσδιακρίτους εἶναι; And *Ricciolus* begins his Chapter of the Solſtitial Obſervations with theſe words, *Merito* Snellius, *in notis ad obſervationes* Haſſiacas, *pronunciavit, Herculei eſſe laboris vitare in* Solſtitiis *obſervandis errorem quadrantis diei*, and this becauſe of the exceeding ſlowneſs of the change of the Sun's Declination on the day of the Tropick, being not a quarter of a Minute in 24 Hours. This indeed would make it very difficult, nor would any Inſtruments ſuffice to do it, were the moment of the Tropick to be determined from one ſingle Obſervation. But by three ſubſequent Obſervations made near the Tropick, at proper intervals of time, I hereby deſign to ſhew a Method to find the moment of the Tropicks capable of all the exactneſs the moſt Accurate can deſire; and that without any conſideration of the Parallax of the Sun, of the Refractions of the Air, of the greateſt Obliquity of the Ecliptick, or Latitude of the Place: All which are required to aſcertain the times of the Equinoctials from Obſervation, and which being faultily aſſumed, have occaſioned an Error of near three Hours in the times of the Equinoctials deduced from the Tables of the Noble *Tycho Brahe* and *Kepler*,

Kepler, the Vernal being ſo much later, and the Autumnial ſo much earlier than by the *Calculus* of thoſe Famous Authors.

Now before we proceed, it will be neceſſary to premiſe the following *Lemmata*, ſerving to demonſtrate this Method, *viz.*

1. That the motion of the Sun in the Ecliptick, about the time of the Tropicks, is ſo nearly equable, that the difference from equality is not ſenſible, from five days before the Tropick, to five days after: and the difference ariſing from the little inequality that there is, never amounts to above $\frac{1}{4}$ of a ſingle Second in the Declination, and this by reaſon of the nearneſs of the *Apogæon* of the *Sun* to the Tropick of *Cancer.*

2. That for five Degrees before and after the Tropicks, the differences whereby the Sun falls ſhort of the Tropicks, are as the Verſed Sines of the Sun's diſtance in Longitude from the Tropicks, which Verſed Sines in Arches under five Degrees, are beyond the utmoſt nicety of ſenſe, as the Squares of thoſe Arches. From theſe two follow a Third:

3. That for five days before and after the Tropicks, the Declination of the Sun falls ſhort of the utmoſt Tropical Declination, by Spaces which are in duplicate proportion, or as the Squares of the Times by which the Sun is wanting of or paſt the moment of the Tropick.

Hence it is evident that if the Shadows of the Sun, either in the Meridian or any other Azimuth, be carefully obſerved about the time of the Tropicks, the Spaces whereby the Tropical ſhade falls ſhort of, or exceeds thoſe at other times, are always proportionable to the Squares of the Intervals of Time between thoſe Obſervations and the true time of the Tropick, and conſequently if the Line, on which the Limits of the ſhade is taken, be made the Axis, and the correſpondent times from the Tropick expounded by Lines, be erected on

their respective Points in the Axis as ordinates, the extremities of those Lines shall touch the Curve of a Parabola; as may be seen in the Figure: Where a, b, c, e, being supposed Points observed, the Lines aB, bC, cA, eF, are respectively proportional to the times of each Observation before or after the Tropical Moment in *Cancer*.

This premised, we shall be able to bring the Problem of finding the true time of the Tropick by three Observations, to this Geometrical one: having three Points in a Parabola A, B, C, or A, F, C given, together with the direction of the Axis, to find the Distance of those Points from the Axis. Of this there are two cases, the one when the time of the second Observation B is precisely in the middle time between A and C: In this case putting t for the whole time between A and C, we shall have Ac the interval of the remotest Observation A from the Tropick by the following Analogy.

As $2ac - bc$ to $2ac - \frac{1}{2}bc$ :: So is $\frac{1}{2}t$ or AE : to Ac the time of the remotest Observation A from the Tropick.

But the other case when the middle Observation is not exactly in the middle between the other two times, as at F, is something more operose, and the whole time from A to C being put $= t$, and from A to F $= s$, $ce = c$, and $bc = b$, the Theorem will stand thus $\frac{ttc - bss}{2tc - 2bs} = Ac$ the time sought.

To illustrate this Method of Calculation it may perhaps be requisite to give an Example or two for the sake of those Astronomers that are less instructed in the Geometrical part of their Art.

Anno 1500 *Bernard Walther* in the Month of *June* at *Nuremburg* observed the Chord of the distance of the Sun from the *Zenith* by a large Parallactick Instrument of *Ptolemy*, as follows:

June

June 2. 45467.		and	*June* 8. 44975.	
June 9. 44934.			*June* 12. 44883.	
June 16. 44990.			*June* 16. 44990.	

In both which cases the middle time is exactly in the middle between the extreams, and therefore in the former three, $ac = 533$, $bc = 477$ and t, the time between being 14 days, by the first Rule, the time of the Tropick will be found by this Proportion, as 589 to $827\frac{1}{2}$: : So $\frac{1}{2}$ t or 7 days to 9 days $20^{h.}\,2'$. whence the Tropick *Anno* 1500 is concluded to have fallen *June* $11^{d.}$ $20^{h.}\,2'$. In the latter three, ac is $= 107$, and $bc = 15$, and the whole interval of Time is 8 days $=$ to t; whence as 199 : to $206\frac{1}{2}$: : so is 4 days to $4^{d.}\,3^{h.}\,37'$. which taken from the 16*th.* day at Noon, leaves $11^{d.}\,20^{h.}\,23'$. for the time of the Tropick, agreeing with the former to the third part of an hour.

Again, *Anno* 1636, *Gassendus* at *Marseilles* observed the Summer Solstice by a *Gnomon* of 55 Foot high, in order to determine the Proportion of the *Gnomon* to the Solstitial shade, and he hath left us these Observations, which may serve as an Example for the second Rule.

June 19. *St. N.* shadow	31766	parts, whereof the *Gnomon* (was 89428.
June 20.	31753	
June 21.	31751	
June 22.	31759	

These being divided into two setts of three Observations each, *viz.* the 19th. 20th. and 22th. and the 19th. 21th. and 22th. we shall have in the first three, $c = 13$ and $b = 7$, $t = 3$ days, $s = 1$, and in the second $c = 15$ and $b = 7$, $t = 3$ and $s = 2$. Whence according to the Rule, the 19*th.* day at Noon the Sun wanted of the Tropick a time proportionate to one day, as $ttc - ssb$ to $2tc - 2bs$, that is, as 110 to 64 in the first sett, or

107 to 62 in the ſecond ſet; that is, $1^{d.}\ 17^{h.}\ 15'$. in the firſt, or $1^{d.}\ 17^{h.}\ 25'$. in the ſecond ſett: So that we may conclude the Moment of the Tropick to have been *June* $10^{d.}\ 17^{h.}\ 20'$. in the Meridian of *Marſeilles*.

Now that theſe two Tropical times thus obtained, will be found to confirm each others exactneſs from their near agreement, appears by the interval of time between them; *viz.* $1^{d.}\ 2^{h.}\ 30'$. leſs than 136 *Julian* years: whereof $1^{d.}\ 1^{h.}\ 8'$. ariſes from the defect of the length of the Tropical Year from the *Julian*, and the reſt from the Progreſſion of the Sun's *Apogæon* in that time; ſo that no two Obſervations made by the ſame Obſerver in the ſame place, can better anſwer each other, and that without any the leaſt Artifice or Force in the management of them.

What were the Methods uſed by the Ancients to conclude the hour of the Tropicks, *Ptolemy* has no where delivered; but it were to have been wiſhed that they had been aware of this, that ſo we might have been more certain of the moments of the Tropicks we have received from them, which would have been of ſingular uſe to determine the Queſtion, Whether the Sun's *Apogæon* be fixt in the Starry Heaven; or if it move, what is the true motion thereof? It is certain, that if we take the Account of *Ptolemy*, the Tropick ſaid to be obſerved by *Euctemon* and *Meton*, *Junii* 27. *manè*, *Anno* 432 *ante Chriſtum*, can no ways be reconciled without ſuppoſing the Obſervation made the next day, or *June* 28*th*. in the Morning. And *Ptolemy*'s own Tropick obſerved in the Third Year of *Antoninus*, *Anno Chriſti* 140, was certainly on the 23*th*. and not the 24*th*. day of *June*; as will appear to thoſe that ſhall duly conſider and compare them with the length of the Year deduced from the diligent and concordant Obſervations of thoſe two great Aſtronomical *Genii*, *Hipparchus* and *Albatâni*; eſtabliſhed and confirmed by the concurrence

of

of all the Modern Accuracy. For these Observations give the length of the Tropical Year such as to anticipate the *Julian* Account only one day in 300 Years; but we are now secure that the said Period of the Sun's Revolution does anticipate very nearly three days in 400 Years; so that the *Tables* of *Ptolemy* founded on that Supposition, do err about a whole day in the Sun's Place, for every 240 Years. Which principal Error in so Fundamental a Point, does vitiate the whole Superstructure of the *Almagest*, and serves to convict its Author of want of Diligence, or Fidelity, or both.

But to return to our Method, the great Advantage we have hereby, is, that any very high Building serves for an Instrument, or the top of any high Tower or Steeple, or even any high Wall whatsoever, that may be sufficient to intercept the Sun, and cast a true shade: Nor is the Position of the Plane on which you take the shade, or that of the Line therein, on which you measure the Recess of the Sun from the Tropick, very material; but in what way soever you discover it, the said Recess will be always in the same Proportion, by reason of the smallness of the Angle, which is not six Minutes in the first five days: Nor need you enquire the height or distance of your Building, provided it be very great, so as to make the Spaces you measure large and fair. But it is convenient that the Plane on which you take the shade be not far from Perpendicular to the Sun, at least not very Oblique, and that the Wall which casts the shade, be straight and smooth at top, and its Direction nearly East and West, for Reasons that will be well understood by a Reader skilful in the Doctrine of the Sphere. And it will be requisite to take the Extream greatest or least deviation of the shadow of the Wall, because the shade continues for a good time at a stand, without alteration, which will give the Observer leisure to be assured of what he does, and not be

surprized

ſurprized by the quick tranſient motion of the ſhade of a ſingle Point at ſuch a diſtance. The Principal Objection is, that the *Penumbra* or Partile ſhade of the Sun is in its extreams very difficult to diſtinguiſh from the true ſhade, which will render this Obſervation hard to determine nicely. But if the Sun be tranſmitted through a *Teleſcope*, after the manner uſed to take his *Species* in a *Solar Eclipſe*, and the upper half of the Object-glaſs be cut off by a Paper paſted thereon, and the exact upper Limb of the Sun be ſeen juſt Emerging out of, or rather contingins the *Species* of the Wall, (the Poſition of the *Teleſcope* being regulated by a fine Hair extended in the *Focus* of the Eye-glaſs,) I am aſſured that the limit of the ſhade may be obtained to the utmoſt exactneſs: And of this I deſign to give a *Specimen* by an Obſervation to be made in *June* next, by the help of the High Wall of St. *Paul's* Church, *London*, of which ſome following Tranſaction may give an Account. In the mean time what I have premiſed may ſuffice to ſet others at work, where ſuch or higher Buildings are to be met with. I ſhall only Advertiſe, that the Winter-Tropick by this Method may be more certainly obtained than the *Summer's*, by reaſon that the ſame *Gnomon* does afford a much larger *Radius* for this manner of Obſervation.

III. *An*